BEETLE HAZARD CLASSIFICATION SYSTEMS

FOR

PONDEROSA PINE TREES

By

Floyd A. Johnson
Pacific Northwest Forest and Range Experiment Station

Index

1. Summary

1.1 Removing trees that are about to die from beetles is certainly an accepted and, very likely, an acceptable management procedure for the pine forests of western United States.

1.2 Beetles have been consistently responsible for a large share of pine mortality, and the removal of trees susceptible to beetles should reduce timber volume losses, increase growth on residual trees, and help to control the insects.

1.3 For this report, a susceptible pine tree has been defined as one that will die from beetles within 10 years.

1.4 The purpose of this report is to announce results of an attempt to discover the best system for identifying susceptible trees.

1.5 Obviously, identification cannot be accomplished without error. Some trees called susceptible would not die if left uncut. Other trees, called nonsusceptible, will die.

1.6 For this report, the <u>best</u> system has been defined as one that satisfied two criteria:

a) The best system should identify as susceptible the greatest possible proportion of the total number of trees that would die from beetles, if left uncut;

b) the best system should not identify as susceptible more than about 20 percent of the original <u>total</u> number of trees.

1.7 Data from permanent plots has shown that about five percent of all trees are susceptible. Criterion (b) above should therefore be adequate in that any identification system at least has a chance of identifying <u>all</u> susceptible trees. Criterion (b) may also be reasonable since a moderately heavy sanitation cut (e.g., 20 percent) will likely be necessary to justify any logging operation.

1.8 Identification of susceptible Portion of Stand trees is customarily accomplished by observing characteristics of individual trees, assigning trees to tree classes according to some tree classification system, and then combining tree classes into two groups--a susceptible group and a nonsusceptible group.

1.9 In this report, the nonsusceptible group of tree classes was called Hazard Class I, the susceptible group was called Hazard Class II, and the entire procedure which results in a segregation of trees into two groups was called Hazard Classification.

1.10 The tree classification systems used for hazard classification and considered in this report are of two general types. One of these types covers <u>established</u> tree classification systems such as the Keen and the Salman-Bongberg systems. They are established in the sense that they have been described in forestry literature and were actually used for hazard classification. Some of these established systems were not designed specifically for hazard classification.

The other general type covers new tree classification systems developed in the course of the analysis which led to this report.

1.11 Among hazard classification systems which were developed from established tree classification systems, four were apparently superior. These were a hazard system based on tree "vigor" classes with vigor classes 3 and 4 in the susceptible or Hazard Class II category; a hazard system based on the Salman-Bongberg "risk" classes with risk classes 3 and 4 in the susceptible category; a hazard system based on "old penalty" classes with penalty classes 4 through 9 in the susceptible category; and a hazard system based on "new penalty" classes with penalty classes 6 through 9 in the susceptible category. The hazard system based on "risk" tree classes seemed to have an advantage over the other three superior systems in terms of the consistency with which the criteria given in paragraph 1.6 above were satisfied.

1.12 Among hazard classification systems developed from new tree classification systems, two were found to be superior. Under one of these systems the susceptible tree classes were:

a) Trees with any amount of twig injury,

b) trees with no twig injury, but with thin needle complement.

Under the other superior system, the susceptible tree classes were:

a) Trees with any amount of twig injury,

b) trees with no twig injury, but with short needles.

These two hazard systems were comparable in effectiveness (as judged by the criteria in paragraph 1.6) to the four hazard systems discussed in paragraph 1.11 above which were developed from established tree classification systems. However, it was possible to test them on only one set of data and there is no evidence for consistency as there was for the hazard system developed from the Salman-Bongberg risk classes.

1.13 Hazard classification systems developed from <u>new</u> tree classification systems which were based on more than two tree characteristics were not more effective than the best of those based on two tree characteristics.

1.14 An analysis leading to an abortive discriminant function indicated that twig injury, branch injury, needle complement, and needle length were the four most effective tree characteristics for predicting mortality in ponderosa pine. This evidence was supported by results from other analyses.

1.15 Hazard classification systems developed from a simplified penalty system were reasonably effective, and they may deserve future consideration. However, they are apparently not quite as effective as the hazard systems discussed in paragraphs 1.11 and 1.12.

1.16 In general, there was insufficient evidence to suggest that the widely recognized Salman-Bongberg tree classification system should be supplanted. On the other hand, there is some evidence to indicate that simpler and more objective tree classification systems may produce results at least comparable to those given by the Salman-Bongberg system.

2. Introduction

There is considerable evidence to indicate that beetles[1/] are

---

1/ The word beetles as used in this report refers collectively to western pine beetle, mountain pine beetle, various species of *Ips* and various species of flathead borers.

---

responsible for a large share of total ponderosa pine mortality in Oregon and California. Using data from 30 plots in Oregon, Keen (1)[2/]

2/ Numbers in parentheses ~~re~~fer to literature cited on page 41.

---

found beetle-killed trees to be 90 percent of all trees that died from natural causes over the ten-year period 1938 to 1948. The corresponding figure from California (Blacks Mountain Data) for approximately the same time period was 89 percent. Dunning (2), using data for an earlier period, reported beetles as the "greatest single cause of mortality." However, in his case this cause accounted for only 35 percent of all ponderosa pine trees dying from 1910 to 1925 on 25 permanent sample plots.

Foresters for years have attempted to reduce this beetle-caused mortality and to control the insects by removing susceptible trees before they become infested. Since susceptible trees had to be identified before they could be removed, a classification problem was created. An abstract representation of this problem has been provided in table 2.1.

Table 2.1

Abstract Representation of a

Beetle Hazard Classification Problem

Beetle Hazard Class	Number of trees that actually survive beetle attacks for x years.	Number of trees that actually die from beetles within x years.	Total
I Number of trees expected to survive beetle attacks for x yrs. (leave trees)	A	C	E = A + C
II Number of trees expected to die from beetles within x yrs. (cut trees)	B	D	F = B + D
Total	G = A + B	H = C + D	J = A + B + C + D

U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FORM FS-62

In table 2.1 the F high hazard trees are those possessing some characteristics or combination of characteristics which indicate susceptibility in the sense that they are expected to die within some definite period of years. All F trees will presumably be removed in a sanitation cut, but B of these are, in fact, not susceptible and would therefore be removed needlessly. Of the E trees not cut, C should be cut because they are actually susceptible and therefore will die from beetles.

Thus B and C represent errors of misclassification, C being trees that die when they are expected to live and B being trees that live when they are expected to die. The problem is to find which of many possible hazard classification systems developed from tree characteristics is best in terms of these misclassifiaction errors. Criteria for selecting the best hazard classification system will be presented later in Chapter 5.

Each of the two hazard classes in any hazard classification system may be nothing more than a single tree class from some tree classification system. Thus if trees are classified solely on needle color, the green needle tree class might correspond to hazard class I and the yellow needle tree class might correspond to hazard class II.

If several tree characteristics are used for the tree classification system, there could be several tree classes available for segregation into the two hazard classes. Thus hazard class I might include trees with green needles and no twig injury, leaving trees with green needles and some twig injury and also all trees with yellow needles for hazard class II.

If trees are classified according to some established tree classification system such as the Keen (4) or the Dunning (2) systems, the resultant classes can also be combined into the two hazard classes of a hazard classification system. For example, hazard class I might include risk classes 1, 2, and 3 of the Salman-Bongberg tree classification system (3). Hazard class II would, in this case, be identical with risk class 4.

For purposes of this report, the term "hazard classification system" refers only to systems of the type illustrated in table 2.1, and the term "tree classification system" refers to <u>any</u> other procedure for segregating trees into groups.

Throughout this report, 10 years were used as the period during which trees are expected either to remain alive or to die to qualify for hazard class I or II. Both Keen (1) and Bongberg (3) used this period for their analyses. Since trees sometimes take a long time to die, a shorter period may not be appropriate. On the other hand, if the chosen tree characteristics are really associated with susceptibility, the effect should be apparent by 10 years.

not necessarily
Furniss: 17 yrs.

Information of the type shown in table 2.1 can only be supplied by special studies in which each of a large number of trees is described in detail initially and then observed through time for the occurrence of death. Two studies of this kind are covered in this report. One will be called the California study and the other the Oregon study. In the analysis which led to this report, those few trees in the two studies which died from natural causes other than beetles within the 10 year period were not used.

3. California Study

Eleven plots from 5 to 20 acres in size were established on the Blacks Mountain Experimental Forest during the years 1938-1942. There were 2,551 trees on these eleven plots, and 26 observations were recorded initially for each tree. General information about the plots is given in table 3.1, and the 26 observations are listed in table 3.2.

Tree characteristics represented by observations 6 through 26 in table 3.2 were recorded by subclasses (e.g., subclasses for observation 9 in table 3.2 are needles long, medium, or short). For some characteristics the contrasts among subclasses involved fine distinctions which were certainly subjective and perhaps not meaningful. The number of subclasses were reduced in these cases by combining subclasses. In addition, some characteristics were deleted altogether, either because they were not observed consistently over all trees on all plots or because the same rating was given consistently to two observations (e.g., this was true of top needle length and midneedle length). Those tree characteristics which were retained for the hazard classification analysis are listed in table 3.3 along with their condensed subclasses.

Every year since these observations were made, each tree was reexamined. When death occurred, the date and the cause of death were recorded.

During the 10-year period since the observations were first made, 13 trees were lost to the study from natural causes other than beetles. Of the 2,538 trees remaining, 107 died from beetles and 2,431 survived the 10-year period.

Table 3.1--Plot information

California Study

Plot no.	Estab-lish-ment date	Plot size acres	Number of Ponderosa pine trees		
			Dying from natural causes other than beetles within the 10-yr. period from establishment date	Surviving at least 10 yrs. from es-tablishment date	Dying from beetles within the 10-yr. period from estab-lishment date
1	1939	10	1	176	10
2	1939	10	3	193	23
3	1939	10	0	96	7
4	1939	10	2	181	7
5	1938	5	4	111	8
6	1942	10	0	209	11
7	1938	20	1	342	10
8	1939	20	1	160	4
9	1941	20	0	360	7
10	1941	20	0	269	18
11	1942	20	1	334	2
	Total		13	2,431	107

Change of Risk Plots

329-10 Cut

M.C. Plots

Table 3.2--Observations recorded for trees on the California plots.

Observation Number	Observations
1	Diameter outside bark at breast height
2	Keen class
3	Dunning class
4	Risk class
5	Vigor class
6	Top needle complement (needles per twig)
7	Midneedle complement (needles per twig)
8	Top needle length
9	Midneedle length
10	Top needle color
11	Midneedle color
12	Top crown density
13	Midcrown density
14	Top twig injury
15	Midtwig injury
16	Top branch injury
17	Midbranch injury
18	Current top kill
19	Old top kill
20	Spike top
21	Dominance
22	Age
23	Crown length
24	Crown symmetry
25	Crown width
26	Top shape

Table 3.3--Revised subclasses for tree characteristics used in the analysis of the California data.

Tree characteristic	Subclasses
Top needle complement	1) Dense and heavy contrast 2) Medium 3) Thin and thin contrast 4) Top killed
Top needle length	1) Long and long contrast 2) Medium 3) Short and short contrast 4) Top killed
Top needle color	1) Dark 2) Medium 3) Off color and top killed
Top twig injury	1) None 2) Some, including top killed
Top branch injury	1) None 2) Some, including top killed
Current top killing	1) None 2) Some
Old top killing	1) None 2) Some
Spike top	1) None 2) Some
Dominance	1) Dominant 2) Codominant 3) Intermediate 4) Suppressed
Age	1) Young 2) Immature 3) Mature 4) Overmature

Table 3.3 (Cont.)

Tree characteristic	Subclasses
Crown length	1) Three-fourths of total tree length 2) One-half " " " " 3) One-fourth " " " "
Crown width	1) Wide 2) Medium 3) Narrow
Top shape	1) Pointed 2) Rounded 3) Flat

4. Oregon Study

Information on each of 30 Oregon plots is given in table 4.1. Each of the 30 plots was 10 acres in size, and they were all established in 1938 or 1939. Observations recorded on each of the trees from the Oregon plots are listed in table 4.2. The number and the nature of the observations made in Oregon varied considerably from those made in California. Only seven tree characteristics were recorded for trees on the Oregon plots (observations 6 through 12 in table 4.2), but five of these were actually combined characteristics (e.g., twig and branch injury were recorded as a single characteristic). Subclasses for each of the seven tree characteristics are listed in table 4.3.

5. Criteria for Selecting the Best Hazard Classification Systems

When Keen (1) defined the purpose of hazard classification as "selecting the highest percentage of killed trees out of the lowest percentage of the green stand," he was suggesting that the proportion D/H (see table 2.1) should be as large as possible and that F/J should be as small as possible. This, of course, is just another way of saying that the B and C misclassification errors should both be as small as possible. He called $\frac{D/H}{F/J}$ the "mortality ratio" and used it roughly as an achievement index for rating various hazard classification systems.

Table 4.1--Oregon plot information

Plot no.	Dying from natural causes other than beetles within the 10-yr. period from establishment date	Surviving at least 10 years from establishment date	Dying from beetles within the 10-year period from establishment date
1	1	211	3
2	2	329	3
3	8	174	14
4	4	113	10
5	2	324	16
6	0	245	14
7	0	123	3
8	0	83	9
9	0	288	11
10	0	251	14
11	0	319	6
12	1	498	15
13	2	292	8
14	2	118	3
15	1	242	13
16	0	198	14
17	5	378	9
18	3	244	15
19	3	279	5
20	2	231	11
21	0	213	17
22	4	293	13
23	0	274	19
24	1	228	5
25	1	213	10
26	0	420	9
27	0	159	11
28	0	149	36
29	0	189	28
30	0	161	53
Total	42	7,239	397

Table 4.2--Observations recorded for trees on the Oregon plots.

Observation number	Observations
1	Diameter outside bark at breast height
2	Keen tree class
3	Vigor tree class
4	Penalty tree class
5	Risk tree class
6	Crown condition
7	Top condition
8	Needle length and complement
9	Needle texture and color
10	Twig and branch injury
11	Fire and lightning injury
12	Mistletoe and disease

Table 4.3--Original subclasses for tree characteristics recorded on the Oregon plots.

Tree characteristic	Subclass	
Crown condition (density)	1. Heavy throughout	
	2. Normal throughout	
	3. Normal on top - open below	
	4. Normal with some open	
	5. Thin - weak below top	
	6. Thin - bunchy at branch ends	
	7. Thin throughout	
	8. Scattered open crown	
	9. Open above - dense below	
	10. Very thin and open	
Top condition (vigor and growth)	1. Vigorous - fast growing	
	2. Normal vigor - slow growth	
	3. Normal vigor - no growth	
	4. Weak thin pointed top	
	5. Weak stagnant top	
	6. Declining vigor in top	
	7. Dying tip of terminal	
	8. Active spike	
	9. Old spike	
	10. Broken top	
Needle length and complement	Length	Complement
	1. Long	Large
	2. Normal	Large
	3. Normal	Normal
	4. Normal	Small
	5. Medium short	Normal
	6. Medium short	Small
	7. Medium short above Normal below	--
	8. Very short	Normal
	9. Very short	Small
	10. Very short above Normal below	--

 (continued)

Table 4.3 (Cont.)

Tree Characteristic	Subclass		
Needle texture and color		Texture	Color
	1.	Heavy coarse	Dark green
	2.	Heavy coarse	Normal green
	3.	Heavy coarse	Light green
	4.	Normal weight	Dark green
	5.	Normal weight	Normal green
	6.	Normal weight	Light green
	7.	Light feathery	Normal green
	8.	Light feathery	Light green
	9.	Light feathery	Gray silvery green
	10.	Any	Fading or off-color
Twig and branch injury	1.	None	
	2.	Few lateral twigs dead, none dying	
	3.	Few lateral twigs dying	
	4.	Many lateral twigs dying	
	5.	Few lateral twigs and branches dead, none dying	
	6.	Few lateral twigs and branches dying	
	7.	Many lateral twigs and branches dead, few dying	
	8.	Many lateral twigs and branches dying	
	9.	Many lateral twigs and branches dead and dying	
Fire and lightning injury	1.	Small fire scar	
	2.	Large fire scar	
Mistletoe and disease	1.	Large amount of mistletoe	
	2.	Small witches brooms	
	3.	Large witches brooms	
	4.	Dendroctonus valens attack	

Keen changed several tree classification systems into corresponding hazard classification systems by combining individual tree classes. The point of importance here is that he obviously used mortality ratio as the criterion for comparing hazard classification systems. Mortality ratio is a convenient criterion, but its adequacy, when used for this purpose, may be questioned. For example, a mortality ratio may be large, and therefore seemingly desirable, only because its denominator, the proportion F/J, is small, but this proportion may not be especially important. A heavier sanitation cut than is indicated by F/J may be necessary to justify the logging operation, and D/H, the numerator of the mortality ratio, may be more important for judging the adequacy of a hazard classification system than the mortality ratio itself.

However, the proportion F/J cannot be ignored completely because this could lead to cutting all trees so that none would be left to die from beetles. Experience has indicated that the proportion of total volume cut in a sanitation cut will normally lie somewhere between 0.15 and 0.25. This same range of proportions will probably apply when the cut is expressed in terms of number of trees as in the F/J proportion of table 2.1.

Perhaps the various hazard classification systems should be evaluated by first establishing an upper limit for the proportion of the original green stand which is placed in hazard class II (i.e., F/J), and then choosing as optimum that system for which the proportion of correctly classified dead trees (i.e., D/H) is largest. This implies that all

values of F/J are equally important up to the established limit, and that the size of the D/H proportion is the sole criterion as long as F/J does not exceed the established limit. For lack of something better, this criterion was used for the comparisons among hazard classification systems which are discussed later in this report.

Those hazard classification systems which are judged best for one study will, of course, not necessarily maintain their superiority when tried elsewhere. The procedure used, therefore, was to try various systems using the California data, and then check them with the Oregon data insofar as possible. The systems judged best on the basis of pooled data from all California plots were also applied to individual California plots in an additional check for consistency.

6. Hazard Classification Systems Developed From Established Tree Classification Systems

The critical proportions, D/H and F/J, as calculated from the pooled (i.e., all plots combined) California data and from the pooled Oregon data, are shown in table 6.1 for each of several hazard classification systems which have been developed from established tree classification systems.

System number 1 in table 6.1 was best in the sense that only a small proportion of the trees that actually died in 10 years would not have been marked for removal. However, an excessively large percentage (41 percent in California and 51 percent in Oregon) of the original green stand would have to be marked for removal under system 1.

U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FORM FS-62

Table 6.1--Critical proportions for hazard classification systems developed from established tree classification systems.

Hazard Classification System					Critical Proportions	
		Description				
No.	Name	Hazard Class I	Hazard Class II	Study	D/H[1/]	F/J[2/]
1	Salman-Bongberg	Risk class 1	Risk classes 2, 3, and 4	California Oregon	0.850 0.903	0.407 0.512
2	Salman-Bongberg	Risk classes 1 & 2	Risk classes 3 & 4	California Oregon	0.757 0.655	0.134 0.196
3	Salman-Bongberg q	Risk classes 1, 2, and 3	Risk class 4	California Oregon	0.542 0.445	0.061 0.067
4	Keen	Age classes 1 & 2	Age classes 3 & 4	California Oregon	0.916 0.818	0.647 0.685
5	Keen	Crown classes A & B	Crown classes C & D	California Oregon	0.393 0.727	0.186 0.430
6	Keen	All of crown classes A & B plus age classes 1 & 2 in crown class C	All of crown class D plus age classes 3 & 4 in crown class C	California Oregon	0.364 0.668	0.164 0.347
7	Vigor	Vigor classes 1 & 2	Vigor classes 3 & 4	California	0.804	0.201
8	Dunning	Dunning classes 1, 2, 3 & 4	Dunning classes 5, 6, 7 & 8	California	0.670	0.437
9	Dunning	Dunning classes 1, 2 & 3	Dunning classes 4, 5, 6, 7 & 8	California	0.776	0.524
10	Old penalty	Penalty classes 1, 2 & 3	Penalty classes 4, 5, 6, 7, 8 & 9	Oregon	0.658	0.208
11	New penalty	Penalty classes 1, 2, 3, 4 & 5	Penalty classes 6, 7, 8 & 9	Oregon	0.653	0.184

1/ Proportion of total dying stand in Hazard Class II.

2/ Proportion of total original green stand in Hazard Class II.

System 3, on the other hand, isolates cut trees in a smaller portion of the original green stand than any other system, but it leaves a large portion of the trees that die from beetles in hazard class I. System 2 is among the most acceptable of those systems shown in table 6.1 from the standpoint of both the D/H and F/J proportions. Systems 7, 10, and 11 also give favorable results, but in these cases results are available only for one study and there is no evidence for consistency as there is for system 2.

The Keen systems were in general poorer than the Salman-Bongberg systems. This substantiates conclusions given in Keen's report (1).

It should be recognized that the judgments made here are arbitrary since they assume that something near a 20 percent sanitation cut is the maximum acceptable.

The critical proportions D/H and F/J are shown separately in table 6.2 for each of the 11 California plots and for two of the best hazard classification systems listed in table 6.1. These are systems 2 and 7.

In only one out of 11 plots did the F/J proportion exceed 20 percent for the Salman-Bongberg system and in this case, the percentage was only slightly above 20 percent. The F/J proportion exceeded 20 percent 6 times out of 11 for the Vigor system. The D/H proportions for individual plots were consistently good under both systems, and neither system appeared to have an advantage in this respect.

All of this evidence seems to indicate that hazard classification system 2 in table 6.1 is superior to the other hazard classification systems which have been developed from established tree classification systems.

Table 6.2

Critical Proportions by Individual California Plots for Hazard Classification Systems Developed from the Salman-Bongberg and the Vigor Tree Classification Systems

Plot number	Hazard Classification System			
	Salman-Bongberg (System 2 in table 6.1)		Vigor (System 7 in table 6.1)	
	D/H	F/J	D/H	F/J
1	1.000	0.167	1.000	0.242
2	0.826	0.171	0.783	0.287
3	0.286	0.126	0.286	0.194
4	0.857	0.207	1.000	0.319
5	0.750	0.168	0.875	0.210
6	0.818	0.105	0.818	0.236
7	0.900	0.145	1.000	0.188
8	0.750	0.073	0.750	0.262
9	0.714	0.104	0.857	0.150
10	0.611	0.109	0.611	0.171
11	0.500	0.068	0.500	0.089

7.--Hazard Classification Systems Developed from New Tree Classification Systems Based on Single Tree Characteristics

In this section, hazard classes are developed directly from single tree characteristics in an attempt to see if the results shown in table 6.1 can be improved upon.

Table 7.1 will serve to illustrate this approach to the hazard classification problem. The critical proportions calculated from table 7.1 (D/H = 72/107 = 0.673 and F/J = 333/2538 = 0.131) suggest that a single tree characteristic, twig injury, has been responsible for a hazard classification system which is about as effective as the best of the multi-characteristic systems shown in table 6.1.

Results in terms of the critical proportions, D/H and F/J, are shown in table 7.2 for several hazard classification systems, all of which are based on single tree characteristics as recorded for the California study.

Most of the systems listed in table 7.2 required a combining of subclasses within a tree characteristic. Thus, in system no. 3, the medium and short needle subclasses were combined for hazard class II. For single characteristics with more than two subclasses, there is more than one way to construct a hazard classification system (e.g., systems 1 and 2 in table 7.2).

Only reasonable systems are shown in table 7.2 for a given tree characteristic. In other words, such obviously nonsusceptible subclasses as "needles long" or "color dark" were never considered for hazard class II. On the other hand, intermediate subclasses such as "needles medium length" and "color medium" were considered available for use in both hazard classes.

Table 7.1

A Hazard Classification System Based on the

Single Tree Characteristic, Twig Injury

(California Data)

Hazard Class	Number of trees alive after 10 years	Number of trees that died within 10 years	Total
I Trees with no twig injury and therefore expected to live for at least 10 years	2,170	35	2,205
II Trees with twig injury and therefore expected to die within 10 years	261	72	333
Total	2,431	107	2,538

Table 7.2--Critical proportions for hazard classification systems developed directly from single tree characteristics.

(California data--all plots combined)

Hazard Classification System				Proportion of total dying stand in Hazard Class II D/H 1/	Proportion of original green stand in Hazard Class II F/J 2/
		Description			
No.	Tree characteristic	Hazard Class I	Hazard Class II		
1	Top needle complement	Dense	Medium, thin, & top killed	0.803	0.388
2	Top needle complement	Dense - Medium	Thin & top killed	0.467	0.097
3	Top needle length	Long	Medium, short, & top killed	0.776	0.331
4	Top needle length	Long and medium	Short & top killed	0.364	0.074
5	Top needle color	Dark	Medium, offcolor & top killed	0.589	0.215
6	Top needle color	Dark and medium	Offcolor & top killed	0.093	0.008
7	Top twig injury	No injury	Some injury	0.673	0.131
8	Top branch injury	No injury	Some injury	0.561	0.089
9	Current top kill	No kill	Some kill	0.140	0.013
10	Old top kill	No kill	Some kill	0.271	0.059
11	Spike top	No spike top	Spike top	0.009	0.007
12	Crown class	Dominants	Codominants, intermediates & suppressed	0.252	0.247
13	Age	Young, immature, & mature	Overmature	0.607	0.407
14	Crown length	75 percent of bole	50 & 25 percent of bole	0.364	0.280
15	Crown width	Wide	Medium & narrow	0.850	0.745
16	Top shape	Pointed & rounded	Flat	0.495	0.193

Diameter outside bark at breast height proved to be completely ineffective for segregating trees into hazard classes.

Under the assumptions that something close to 20 percent will be the highest acceptable intensity for a sanitation cut, and that at least 50 percent of all mortality must be captured in the sanitation cut, systems 5, 7, and 8 in table 7.2 are the only ones which qualify. Results in terms of the critical proportions by individual California plots for these three systems are shown in table 7.3. Note that for twig injury, the D/H proportion fell below 0.50 on only one plot, and the F/J proportion was never appreciably above 0.20. Branch injury was slightly less effective in that the proportion of dead trees correctly placed in hazard class II was less than 0.50 for three of the eleven plots. Seven plots failed to qualify in terms of one or both critical proportions when needle color was used. These results, along with those from table 7.2, suggest that top twig injury may be the most effective single tree characteristic to use for hazard classification, that top branch injury is either equally or almost as effective as top twig injury, and that top needle color is somewhat less effective than the other two tree characteristics.

Although twig and branch injuries were recorded together as one observation on the Oregon plots, it was still possible to use the Oregon data to make comparisons against the California results. This was done for twig injury by identifying all subclasses except the first with "some" twig injury and the first subclass with "no" twig injury (see table 4.3). The first four of these subclasses were identified with "no" branch injury, leaving the remaining subclasses for "some" branch injury. Needle color and needle texture were also combined in a single observation for the Oregon plots, and it was necessary again to combine the subclasses shown in table 4.3 to approach the effect of the single characteristic, needle color.

Results for all Oregon plots combined are shown in table 7.4. Twig injury did not maintain its superiority because a large sanitation cut (56 percent) would apparently be required to capture a high percentage of trees that actually would die (77 percent). Branch injury and needle color also proved to be characteristics of questionable value. In these two cases, both critical proportions were borderline in terms of acceptability.

In general, it can probably be said that twig injury, branch injury, and needle color may be moderately successful for hazard classification when used as single tree characteristics. None of these single tree characteristics appears to be as good as the best of the multicharacteristic systems shown in table 6.1.

Table 7.4--Critical proportions for hazard classification systems developed directly from single tree characteristics. (Oregon data - all plots combined)

Hazard Classification System				Critical Proportions	
		Description			
No.	Tree characteristic	Hazard Class I	Hazard Class II	D/H	F/J
1	Twig injury	No twig injury Subclass 1	Some twig injury Subclasses 2, 3, 4, 5, 6, 7, 8, 9	0.772	0.555
2	Branch injury	No branch injury - Subclasses 1, 2, 3, 4	Some branch injury - Subclasses 5, 6, 7, 8 & 9	0.587	0.282
3	Needle color	Dark and normal green - Subclasses 1, 2, 4, 5, 7	Light green, silvery green, fading, and offcolor	0.580	0.251

8. Hazard Classification Systems Developed From New Tree Classification Systems Based on Two Tree Characteristics

There are several ways of combining two tree characteristics to create a so-called "new" tree classification system. The simplest way involves combining two tree characteristics, each of which has only two subclasses (i.e., none and some). Four tree classes are possible in this case; none-none, none-some, some-none, and some-some. These four tree classes can be symbolized by 0-0, 0-1, 1-0, and 1-1 with 0 meaning none and 1 meaning some. For the California data, branch injury and twig injury are the only tree characteristics which have only two subclasses. Information leading to the combination of branch and twig injury is presented in table 8.1.

One way to construct a hazard classification system from the tree classes in table 8.1 would be to put tree classes 2, 3, and 4 in hazard class II, but this would give the same results listed for the single tree characteristic, twig injury, in table 7.2 (i.e., D/H = 0.673 and F/J - 0.131). No other way of constructing a hazard system would give nearly as good results, and the obvious conclusion is that the addition of branch injury to twig injury adds nothing to the effectiveness of hazard classification at least insofar as the California data is concerned.

Table 8.1

Tree Classes Developed From Bark and Twig Injury

California Data

(All plots combined)

Tree class	Twig injury 0 = none 1 = some	Bark injury 0 = none 1 = some	No. of trees dying in 10 years	No. of trees in original green stand	Proportion of trees dying in 10 years	Proportion of trees in original green stand
1	0	0	35	2,200	0.327	0.867
2	0	1	0	5	0.000	0.002
3	1	0	13	114	0.121	0.045
4	1	1	59	219	0.552	0.086
Total			107	2,538	1.000	1.000

In combining two tree characteristics, one or both of which have more than two subclasses, there are additional possibilities in terms of grouping tree classes into hazard classes. The characteristics, twig injury and needle length, will be used to illustrate this in table 8.2.

There are two possibilities for constructing a hazard classification system from information in table 8.2. One involves taking tree classes 4, 5, and 6 for hazard class II, but this is the same as using the single tree characteristic, twig injury. The other possibility is to take tree classes 3, 4, 5, and 6 for hazard class II. This has the effect of increasing the D/H proportion from 0.673 (see table 7.2) to 0.748. Although the F/J proportion also increases in this case from 0.131 to 0.168, it is still acceptably low. Thus twig injury, regardless of needle length, and short needles in the absence of twig injury could be taken as the two criteria indicative of high hazard.

Various combinations of two tree characteristics were tried using the California data, and results for the most effective hazard classification systems are shown in table 8.3.

The best combinations of two tree characteristics were twig injury with needle complement and twig injury with needle length. Considering all of the hazard classification systems in table 8.3, there was evidence of some improvement over the single tree characteristic systems listed in table 7.2. In effect, one characteristic is apparently complementing the other in its ability to identify trees which will die.

Table 8.2--Tree classes developed from twig injury and on needle length

(California data)

Tree class	Twig injury 0 = none 1 = some	Needle length 0 = long 1 = medium 2 = short	No. of trees dying in 10 years	No. of trees in original green stand	D/H Proportion of trees dying in 10 years	F/J Proportion of trees in original green stand
1	0	0	17	1,599	0.159	0.630
2	0	1	10	513	0.093	0.202
3	0	2	8	93	0.075	0.037
4	1	0	7	100	0.065	0.039
5	1	1	34	138	0.318	0.054
6	1	2	31	95	0.290	0.038
Total			107	2,538		

Table 8.3

Critical Proportions for Hazard Classification Systems

Developed Directly from Combinations of Two Tree Characteristics

(California Data--All Plots Combined)

Hazard Classification System			Critical Proportions	
No.	Tree characteristic	Combinations of characteristics which lead to placing a tree in hazard class II	D/H	F/J
1	Top needle complement & top twig injury	a) Complement dense or medium & some twig injury b) Complement thin with or without twig injury	.766	.169
2	Top needle complement & top branch injury	a) Complement thin b) Complement dense or medium & some branch injury	.682	.136
3	Top needle complement & crown length	a) Complement thin b) Complement dense or medium & crown length	.514	.130
4	Top needle length & top needle color	a) Needle length short or killed b) Needle length medium & color medium or off c) Needle length long & color off	.589	.184
5	Top needle length & top twig injury	a) Some twig injury b) Needle length short with or without twig injury	.748	.168
6	Top needle length & top branch injury	a) Some branch injury b) Needle length short	.654	.130

 (Continued)

Table 8.3 (Cont.)

Hazard Classification System			Critical Proportions	
No.	Tree characteristic	Combinations of characteristics which lead to placing a tree in hazard class II	D/H	F/J
7	Top needle length & tree age	a) Needle length short or killed b) Needle length medium & tree overmature	.636	.209
8	Top needle length & top shape	a) Needle length short with any top shape b) Needle length medium with top shape flat c) Top killed	.532	.188
9	Top needle length & top shape	a) Needle length short with any top shape b) Needle length medium with top shape flat c) Top killed	.551	.141
10	Top needle color & top twig injury	a) Some twig injury b) Color off & no twig injury	.682	.133
11	Top needle color & top branch injury	a) Some branch injury b) Color off & no branch injury	.570	.091
12	Top needle color & tree age	a) Tree overmature & needle color other than dark b) Tree mature & needle color other than dark	.561	.190
13	Top twig injury & dominance	a) Some twig injury b) Suppressed crown class	.701	.178

Table 8.3 (Cont.)

Hazard Classification System			Critical Proportions	
No.	Tree characteristic	Combinations of characteristics which lead to placing a tree in hazard class II	D/H	F/J
14	Top twig injury & dominance	a) Some twig injury b) Intermediate & suppressed crown classes	.729	.205
15	Top twig injury & crown length	a) Some twig injury b) Crown length 1/4 of total tree length	.682	.161
16	Top branch injury & dominance	a) Some branch injury b) Intermediate & suppressed crown classes	.626	.163
17	Top branch injury & dominance	a) Some branch injury b) Suppressed crown class	.579	.135
18	Top branch injury & crown length	a) Some branch injury b) Crown length	.570	.121

The best of the two characteristic hazard classification systems appeared to be about as effective as the best of those systems listed in table 6.1 which were developed from established tree classification systems such as the Salman-Bongberg or the Vigor systems. However, unlike some of the systems in table 6.1, it was not possible to check the systems in table 8.3 for consistency by applying them to the Oregon data.

9. Hazard classification systems developed from new tree classification systems based on more than two tree characteristics.

Procedures discussed in the previous section for creating tree classes and then for condensing these tree classes into two hazard classes can be extended to cover combinations involving more than two tree characteristics. The total possible number of hazard classification systems that could be developed from combinations of more than two tree characteristics is very large. Only the more promising of these were examined, and none of those examined were appreciably better than the best of the two characteristic systems shown in table 8.3.

10.--Hazard classification systems developed from a simplified penalty system.

Under the so-called penalty tree classification systems (1), individual tree characteristics were given weights (i.e., penalty scores) which were assumed correlated with the probability of beetle attacks and with the subsequent death of the tree.

Hazard classification systems developed from these penalty tree classification systems were shown in table 6.1 to be fairly effective. However, the weights applied to tree characteristics under these systems were somewhat arbitrary and certainly subjective. A test was therefore made in this study of a simplified penalty system in which the score "0" or "1" was given to each of 12 characteristics for a single tree (see table 3.3). If the subclass tallied for a particular characteristic was not associated with susceptibility, the tree was given a score of "0". If it was associated with susceptibility, the tree was given a score of "1". In a sense, this is giving unit weight to each tree characteristic, and it is therefore no less subjective or arbitrary than the previous penalty systems. However, it is considerably simpler.

Susceptible and nonsusceptible subclasses are shown in table 10.1 for each of the 12 tree characteristics tallied on the California plots.

The penalty class for a tree was defined as the sum of the penalty scores. Penalty classes were then combined as before into two hazard classes. Results for individual California plots and for all plots combined in terms of critical proportions are given in table 10.2.

The results for all plots combined were not quite as favorable as results for the more complicated penalty systems (see systems 10 and 11 in table 6.1). Perhaps this means that the rather involved weighting procedure for tree characteristics used previously was actually effective.

Table 10.1.--Susceptible and nonsusceptible subclasses for each of 12 tree characteristics.

Tree characteristics	Nonsusceptible subclasses score = 0	Susceptible subclasses score = 1
Top needle complement	1) Dense & heavy contrast 2) Medium	3) Thin & thin contrast 4) Top killed
Top needle length	1) Long & long contrast 2) Medium	3) Short & short contrast 4) Top killed
Top needle color	1) Dark 2) Medium	3) Off color & top killed
Top twig injury	1) None	2) Some
Branch injury	1) None	2) Some
Current top kill	1) None	2) Some
Old top kill	1) None	2) Some
Spike top	1) None	2) Some
Dominance	1) Dominant 2) Codominant	3) Intermediate 4) Suppressed
Crown length	1) 3/4 2) 1/2	3) 1/4
Crown width	1) Wide 2) Medium	3) Narrow
Top shape	1) Pointed 2) Rounded	3) Flat

Table 10.2--Critical proportions for hazard classification systems developed from a simplified penalty tree classification system--California data.

Hazard Classification System	Plot no.	Critical Proportions	
		D/H	F/J
Hazard Class I = penalty classes 0 and 1	1	1.000	0.204
	2	0.782	0.287
	3	0.286	0.184
Hazard Class II = penalty classes 2 through 12	4	1.000	0.278
	5	0.875	0.291
	6	0.818	0.261
	7	1.000	0.227
	8	1.000	0.195
	9	0.714	0.201
	10	0.556	0.237
	11	0.500	0.125
	All plots combined	0.776	0.220
Hazard Class I = penalty classes 0, 1, and 2	1	0.700	0.124
	2	0.609	0.185
	3	0.143	0.097
Hazard Class II = penalty classes 3 through 12	4	0.857	0.209
	5	0.500	0.189
	6	0.636	0.147
	7	0.900	0.119
	8	0.750	0.091
	9	0.571	0.102
	10	0.444	0.132
	11	0.500	0.071
	All plots combined	0.598	0.127

11. Some Notes on Analysis Procedure

Analysis procedures which led to the results shown in chapters 6 through 10 leave something to be desired. They are not especially sophisticated, and they are not exhaustive. However, attempts to apply refined procedures were not successful. One of these attempts led to a function (5) for discriminating between trees which will live and trees which will die from beetles. This quantitative analysis procedure, which called for discriminator variables, was suspect from the beginning because the tree characteristics used as discriminator variables were all qualitative. Discriminant function analysis for qualitative variables is apparently not too well established in statistical literature.

When the analysis was completed, six tree characteristics survived as significant discriminators in the following discriminant function:

$$d = X_1 + 2.55X_2 + 1.83X_3 + 13.46X_4 + 7.30X_5 + 5.02X_6$$

where X_1 = crown length

X_2 = needle length

X_3 = needle complement

X_4 = current top kill

X_5 = branch injury

X_6 = twig injury

Appropriate "scores" of the six characteristics for an individual tree would be used in applying this equation to an individual tree. A value for "d" greater than 394.73 would then indicate that the tree was likely to die within 10 years, and if "d" were less than this critical value, survival for at least 10 years would be indicated.

The probability of a misclassification was found to be 14.8 percent, which means that one in every seven trees would be misclassified either by calling it a risk tree or by failing to call it a risk tree. Although this probability does not suggest sensitive discrimination, it is about the best one could expect from data of this kind, and it might be acceptable if it could be trusted. However, the probability of a misclassification requires a discriminant function (d) which is normally, or near normally, distributed. When the equation was applied back to each tree in the California study, it was found to have a decidely skewed distribution for live trees and also for dead trees. For this reason, the discriminant function approach was abandoned.

One reason for considering it here is that others, interested in this general subject, might gain insight through this unsuccessful attempt to find a sophisticated solution to the problem of predicting tree mortality. Another is that the results, although probably not defensible, did substantiate results found under the more primitive analysis procedures of chapters 5 through 9. Thus twig injury, branch injury, needle complement, and needle length were identified under both approaches as the most effective of all tree characteristics for predicting mortality in ponderosa pine. Similarly, the combination of twig injury or branch injury with needle complement or needle length was found in both cases to be more effective than any of the single characteristics acting alone.

There is a question as to whether a highly sophisticated analysis procedure will ever be appropriate with data of this kind. The data is certainly subjective in the sense that no two observers could be expected to describe a tree identically. For example, the distinction between dark and medium green needles is probably much too delicate for objective treatment. Perhaps the methods of chapters 5 through 9 are not inconsistent with the nature of the basic data.

Literature Cited

1. Keen, F. P.
1954. Ponderosa pine tree characteristics indicative of high risk to pine beetle attach. A progress report on studies conducted in eastern Oregon 1938-1952. Pacific Southwest. Forest & Range Expt. Sta.

2. Dunning, Duncan.
1928. A tree classification for the selection forests of the Sierra Nevada. Jour. Agr. Res. 36: 855-771.

3. Salman, K. A., and Bongberg, J. W.
1942. Logging high-risk trees to control insects in the pine stands of northeastern California. Jour. Forestry 40: 533-539.

4. Keen, F. P.
1936. Relative susceptibility of ponderosa pine to bark-beetle attack. Jour. Forestry 34(11): 919-927.

5. Fisher, R. A.
1958. Statistical methods for research workers. 13th ed. Oliver and Boyd, London, England.